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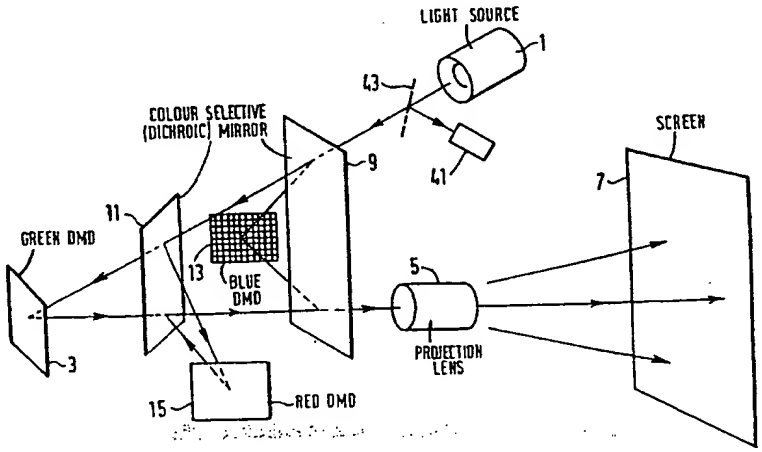
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: DISPLAY SYSTEM



(57) Abstract

A display system includes an arc lamp (1) effective to direct light onto a number of spatial light modulator devices (3, 13, 15). A control circuit (39) is provided effective to modulate the output of the arc lamp (1) in synchronisation with the switching of the spatial light modulator devices.

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GA	Gabon				

DISPLAY SYSTEM

This invention relates to display systems. The invention has particular, although not exclusive, relevance to display systems including a projection system in which light from a light source is modulated by a spatial light modulator device, the modulated light then being projected onto a display.

Spatial light modulators may take several forms. Generally, spatial light modulators may be divided into two types, that is temporally modulated spatial light modulators and amplitude modulated spatial light modulators. One example of a temporally modulated spatial light modulator is a deformable mirror device as described for example in "Deformable Mirror Spatial Light Modulators" by Hornbeck, published in Proceedings of SPIE, Vol. 1150, 6-11 August 1989 in San Diego, California, USA. Such devices comprise an array of mirrored cantilever beam structures, each structure carrying an electrode so as to be electrostatically deflectable between two positions. Thus dependent on the electric field applied to the device, each structure will reflect an incident light beam into one of two alternative light paths, either

towards an optical system for projection onto a display or into a beam dump. Using an array of such structures, each structure being individually addressable, a two dimensional image can be reproduced. The small size and fast switching times of each structure makes such devices usable at video picture data rates enabling the display of television or video moving images on a display screen onto which the reflected and collated beam is projected.

There is however difficulty in displaying low level grey scales using such devices. Generally low level grey scales require a very short burst of light from the deformable mirror device. Thus leads to difficulties in timing the bursts of light because of the finite response time of the spatial light modulator. Furthermore it is necessary to blank the display screen whilst addressing each of the cantilever beam structures whenever the address time exceeds the display period. This leads to dead time in the display device. Finally, artefacts may be produced due to the variable display times of light for each of the grey-scale levels displayed in each picture frame.

An example of an amplitude modulated spatial light modulator is a liquid crystal device comprising a matrix of individually addressable liquid crystal pixels. In such devices, the grey scale is generated by altering the transmission or reflection of each pixel of the liquid crystal device. Such amplitude modulated spatial light modulators also experience problems where it is necessary to display low level grey scales as incident light which is not transmitted (or reflected) by the pixels of the liquid crystal device will be absorbed by the pixels and converted into heat. Furthermore, the discrete nature of the amplitude modulation on a pixel by pixel basis leads to problems of linearity in the grey scale of the light projected on the display, and also problems in general uniformity from area to area of the matrix of pixels.

It is an object of the present invention to provide a display system of the type including a temporally modulated spatial light modulator device wherein the above problems may be at least alleviated.

According to a first aspect of the present invention there is provided a display system including a light source arranged to direct light onto at least one switchable light modulator device, the system including means for modulating the light output of the light source.

According to a second aspect of the present invention there is provided a light source, and means for modulating the light output of the light source so as to increase the efficiency of operation of the light source.

By use of a display system in accordance with the invention, it will be seen that low level grey scales can be displayed whilst avoiding the problems inherent in prior art systems.

It is a feature of the invention that normally amplitude modulated spatial light modulator devices may be operated in a binary manner with the grey scales being operated by temporal modulation. Thus switchable light modulator device may be either a temporally modulated or an amplitude modulated spatial light modulator device.

A number of display systems in accordance with embodiments of the invention will now be described, by way of example only, with reference to the accompanying figures in which:-

Figure 1 is a schematic diagram of a display system;

Figure 2 is a schematic diagram of a spatial light modulator array incorporated in Figure 1;

Figure 3 illustrates the illumination of an element of the device of Figure 2;

Figure 4 is a block schematic diagram of the circuitry used in the power supply circuit for the lamp in the system of Figure 1 in a first embodiment of the invention; and

Figure 5 is a block schematic diagram of alternative circuitry used in the power supply circuit for the lamp of Figure 1 in a second embodiment of the invention.

Referring firstly to Figure 1, the particular example of a display system to be described is arranged to project a colour image onto a display screen. The display system includes a light source 1 which may take any suitable form, for example an arc lamp. The light source 1 is arranged such that the beam from the source is directed onto a planar deformable mirror display device 3 which is in turn arranged to deflect the incident beam so as to direct the beam through a projection lens 5 onto the display screen 7.

Positioned in the light path between the light source 1 and the deformable mirror device 3 are two dichroic mirrors 9, 11. The first mirror 9 is designed and angled to reflect blue light onto a second planar deformable mirror display device 13 and transmit all other incident light. The second dichroic mirror 11 is designed and angled so as to reflect red light onto a third planar deformable mirror device and transmit the remaining green component of the light from the source 1 onto the first deformable mirror display device 3.

Referring now also to Figures 2 and 3, each deformable mirror device 3, 13, 15 comprises an array of m x n deflectable mirror devices, typically 500 x 500 devices for a low resolution display system or 2000 x 2000 devices for a high resolution display system. Each array 17 is connected to an addressing circuit which receives an electronic colour video signal from the control circuit indicated as 21 and addresses each of the mirror devices M_{11} - M_{mn} as, for example, described in the applicants' earlier International Patent Application number PCT/GB92/00002 dated 2nd January 1992 (incorporated herein by reference). Dependent on the applied address signal, each mirror device is caused to take one of two different positions corresponding to an "on state" in which the reflected light is directed in a first path 23 and an "off state" in which the reflected light is directed in a second path 25. The second path 25 is chosen such that light reflected along this direction is directed away from the optical axis of the display system and thus does not pass into the projection lens 5. Thus, each array 17 is capable of representing a two dimensional image, those mirror devices which are set to the "on state" appearing bright and those which

are set to the "off state" appearing dark. By varying the ratio of the "on" period to "off" period, a temporal modulation means of providing grey scale can be achieved as described in earlier UK Patent Application No 2251511. Typically, the display period is divided into a binary sequence of time periods so that the darker elements comprise very short flashes of light.

Turning now particularly to Figure 3 the angle through which each mirror device is deflected between the "on state" and the "off state" is relatively small. Thus in order to achieve good discrimination between the on and off states the incident light beam 27 from the source 1 is directed towards each spatial light modulator 3, 13, 15 at an angle α measured from the normal to each device of around 20^{o}.

When an individual mirror device M is lying at rest parallel to the plane of the array 17, the incident beam 27 is reflected at a corresponding angle of $20^{o}$to the normal along an "off" path 25 into a beam dump (not shown). When the control signal from the addressing circuit 19 sets the mirror device M into a

first deflection state at first angle to the plane of the array 17, the incident beam 27 is reflected along the direction 22 in a further "off" path into the beam dump. When the control signal from the addressing circuit 19 sets the mirror device M into a second deflection state at a second angle to the plane of the array 17, the incident beam 27 is reflected out along the normal to the array along the "on" path 23.

As so far described, the display system is of known form. Turning now to Figure 4, however, in order to enable low level grey scales to be displayed on the screen 7, using the system as described above, the light source 1 is arranged to have a modulated output as will now be described.

Referring to Figure 4, the supply circuit for the light source 1 includes an electro-magnetic interference filter 29 connected across the AC mains input, a power factor correction circuit 31, an energy storage circuit 33 including a large valued storage capacitor, a rectifier circuit 35 and an ignition circuit 37. All these circuit components are common to most lamp supply circuits, and thus their form will be apparent to anyone skilled in the art of

lamp supply circuit design. The supply circuit for the light source 1 differs however from known circuits, however, in that it includes a light output control circuit 39. This control circuit 39 has an input of modulation signals synchronised with the signals from the control circuit 21 provided to the spatial light modulators 3, 13, 15. Control signals from the light output control circuit 39 are provided to a converter and current regulator circuit 42 whose output is in turn full wave rectified by rectifier 35. The light output control circuit 39 also provides start signals to the ignition circuit 37.

A photo detector 41 is arranged in the periphery of the light produced by the light source 1, so as not to intercept the light passing onto the modulators 3, 13, 15 but to provide an indication of the amplitude of the light produced by the source 1. If necessary, a partially reflective mirror, such as that indicated as 43 in Figure 1, may be placed in the light path from the source 1, so as to divert a small portion of the output of the source 1 into the detector 41. The signals from the photo detector 41 are fed back to the light output control circuit 39 so as to modify the control signals provided to the converter and current

regulator 42. Thus the amplitude of the light produced by the light source is stabilised in accordance with the input to control circuit 39. Furthermore, start signals are provided to the ignition circuit 37 when the photodetector 41 detects no light from the light source 1 so as to enable the light source to be reignited where the current through the lamp is insufficient to maintain the arc in the light source 1. This is in addition to the normal function of the ignition circuit when the projector system is initially turned on.

The input modulation signals provided to the control circuit 39 are designed to alter the amplitude of the light source 1 several times (typically 12) during each picture frame of the displayed image in synchronism with the switching cycles of the spatial light modulators 3,13,15. Each pixel may be "on" or "off" for each amplitude of the lamp. It will be seen that by such a means grey scale can be achieved by digital modulation of a light modulator without the problems inherent in prior art systems. The spatial light modulators 3, 13, 15 need to be switched once per lamp amplitude level per frame of the picture being displayed on the screen 7. The display periods

can be made long enough to avoid the necessity for blanking the screen 7 during data loading when low level grey scales need to be displayed, and can conveniently be made equal.

It is found that timing of the switching of the spatial light modulators 3, 13, 15 is easier to achieve in a consistent manner than in prior art systems because of the relatively long and usually equal display periods. The time for addressing the spatial light modulators 3, 13, 15 can easily be arranged to be less than the minimum display period, thus avoiding dead periods on the screen 7. As the display times are usually equal, artefacts produced as a result of short variable display times are reduced. There is now potential to increase the number of grey scale levels.

It is found that there are other benefits to be gained in a system in accordance with the invention in terms of light source efficiency. Where the light source is an arc lamp, lamp efficiency is found to rise considerably with input power. By running the light source at its rated average power but modulating it in a binary manner so as to produce the necessary

grey scale in the image projected on the screen as described above, it is found that the peak power into the lamp rises by a factor of approximately 4. This gives a six-fold increase in light output for peak power levels because of improved lamp efficiency. During the times that the low level grey scales are displayed the light source will be run at very low power levels, that is the output of the light source and its efficiency will be low. As this inefficient operation only occurs at the low brightness and power end of the grey scale it has little effect on the system efficiency. Generally, it is found that the overall effect of lamp modulation is typically a light output gain of 40% for a given lamp power averaged over 10mS periods, based on a series of continuous amplitude levels applied to the lamp without off periods.

Turning now to Figure 5, this figure shows a second embodiment of a control circuit for the light source 1. As many of the components are similar to those shown in Figure 4 like components are correspondingly numbered. The circuit of Figure 5 differs from that of Figure 4 however in that the supply is based on multiple capacitor discharge.

Accordingly a number of capacitors 43_1, 43_2, ... 43_N are provided between a converter and charge control circuit and rectifier all indicated as 45, and a corresponding number of switches 47_1, 47_2..., 47_N. The switches 47_1..., 47_N operate under control of control signals from the control circuit 39 so as to selectively switch the capacitors 43_1..., 43_N to the lamp via the ignition circuit 37. The charge provided by the chosen capacitor 43_1..., 43_N is used to create a very short, intense flash of light of amplitude determined by the charge on the capacitor. Between flashes charge from the energy storage capacitor 33, as modified by a simmer control circuit 49, is used to ensure that the arc of the arc lamp is kept alight. Thus by this means shorter, brighter flashes of light can be achieved by appropriate choice of capacitor 43 than by use of the circuit of Figure 4. Each flash represents the light for a level of the digital grey scale and is synchronised to the switching operation of the deformable mirror devices 3, 13, 15. Furthermore, these short flashes of light enable more efficient operation of the lamp a by use of the circuit of Figure 4.

The use of the loop from the energy storage circuit provides further efficiency gains as the necessity to keep reigniting the arc lamp is avoided. It is found however that the power supply is the main limitation in such circuits, it being very difficult to extinguish an arc where there are short periods of low or zero power. Thus the loop from the energy storage capacitor 33 to the ignition circuit 37 may be omitted in many cases.

It will be appreciated that in either of the lamp supply circuits described herebefore, where a whole frame of a specific level of the grey scale is not to be displayed on the screen 7, the light source 1 does not have to turn on and remains at "simmer" level so as to prevent the necessity of reignition. This thus saves lamp life and reduces heat in the display system.

It will also be appreciated that whilst the embodiments described herebefore utilise temporally modulated light valve systems in the form of deformable mirror devices, the invention is equally applicable to amplitude modulated spatial light modulators, for example liquid crystal arrays. It

will be appreciated that although such spatial light modulators can be operated so as to have inherent grey scale, they can also by use of a system in accordance with the invention be operated in an on/off mode. This thus avoids linearity errors over large scale spatial light modulators such as large scale liquid crystal arrays. Furthermore the problem of heat dissipation in amplitude modulated spatial light modulator systems where low level grey scales are being projected are avoided. Even without taking the lamp grey scale approach, such systems could benefit from the more efficient lamp arising from a continuous pulsed operation.

It will also be appreciated that whilst arc lamps form a particularly appropriate light source for use in a display system in accordance with the invention, any form of light source may be used, for example a fluorescent lamp, or an incandescent lamp.

It will be appreciated that the principle of modulation of light sources can be extended to the drive circuits for discharge lamps in general to improve overall efficiency of the lamps. A continuous series of high energy pulses will give a marked

efficiency gain relative to the average power. The rate of pulsing and peak to mean power ratio will be application dependant. By "discharge lamps" are meant such lamps as arc lamps and fluorescent lamps.

Thus, the invention can be applied to achieve level control, or efficiency gains in non-projector systems which do not use spatial light modulators, for example theatre spotlights, and fluorescent lighting fittings. The modulation input signals synchronised with the signals controlling the spatial light modulations provided to the control circuit in such lamp systems will, of course, be replaced by appropriate control signals.

It will also be appreciated that display systems in accordance with the invention, may include lamp supply circuits which are either AC or DC based.

CLAIMS :

1. A display system including a light source arranged to direct light onto at least one switchable light modulator device arranged to operate in a binary manner so as to produce grey scales by means of temporal modulation, the system including means for modulating the light output of the light source in synchronisation with the operation of the switchable light modulator device.

2. A display system according to claim 1, in which the switchable light modulator device is a spatial light modulator device.

3. A display system according to claim 2, in which the spatial light modulator device is capable of producing grey scales by means of amplitude modulation.

4. A display system according to any one of the preceding claims including means for temporally modulating the light output.

5. A display system according to claim 4, in which the light source is arranged such that the means for temporally modulating increases the efficiency of the light source.

6. A display system according to any one of the preceding claims, including means for amplitude modulating the light output.

7. A display system according to any one of the preceding claims in which the light source is a discharge lamp.

8. A display system according to claim 6 or claim 7, including a bank of energy storage means, and means for selectively connecting chosen ones of the energy storage means to the light source so as to modify the light output of the light source.

9. A display system according to claim 7 or claim 8 when dependent on claim 7, including feedback means effective to determine when the discharge lamp is not operating and to cause operation of an ignition circuit when the discharge lamp is not operating.

10. A display system according to any one of the preceding claims, including means operative to determine the light output of the light source, and means for adjusting the power supplied to the light source dependent on the determined light output.

11. A display system substantially as hereinbefore described with reference to Figure 4 or Figure 5 of the accompanying drawings.

12. A discharge lamp system including means for modulating the light output of the discharge lamp so as to increase the efficiency of the discharge lamp.

13. A system according to claim 12 in which the means for modulating amplitude modulates the output of the discharge lamp.

14. A system according to claim 12 or 13 in which the means for modulating temporally modulates the output of the discharge lamp.

15. A system according to any one of claims 12 to 14 including means operative to determine the light output of the discharge lamp, and means for adjusting

the power supplied to the discharge lamp dependent on the determined light output.

16. A system according to claims 14 or 15 when dependent on claim 14 including a bank of energy storage means, and means for selectively connecting chosen ones of the energy storage means to the discharge lamp so as to modify the light output.

17. A system according to claim 15 or claim 16, including feedback means effective to determine when the discharge lamp is not operating and to cause operation of an ignition circuit.

18. A system according to any one of claims 12 to 17, including means operative to determine the light output of the discharge lamp, and means for adjusting the power supplied to the discharge lamp dependent on the determined light output.

19. An discharge lamp system substantially as hereinbefore described with reference to Figure 4 or Figure 5, of the accompanying drawings.

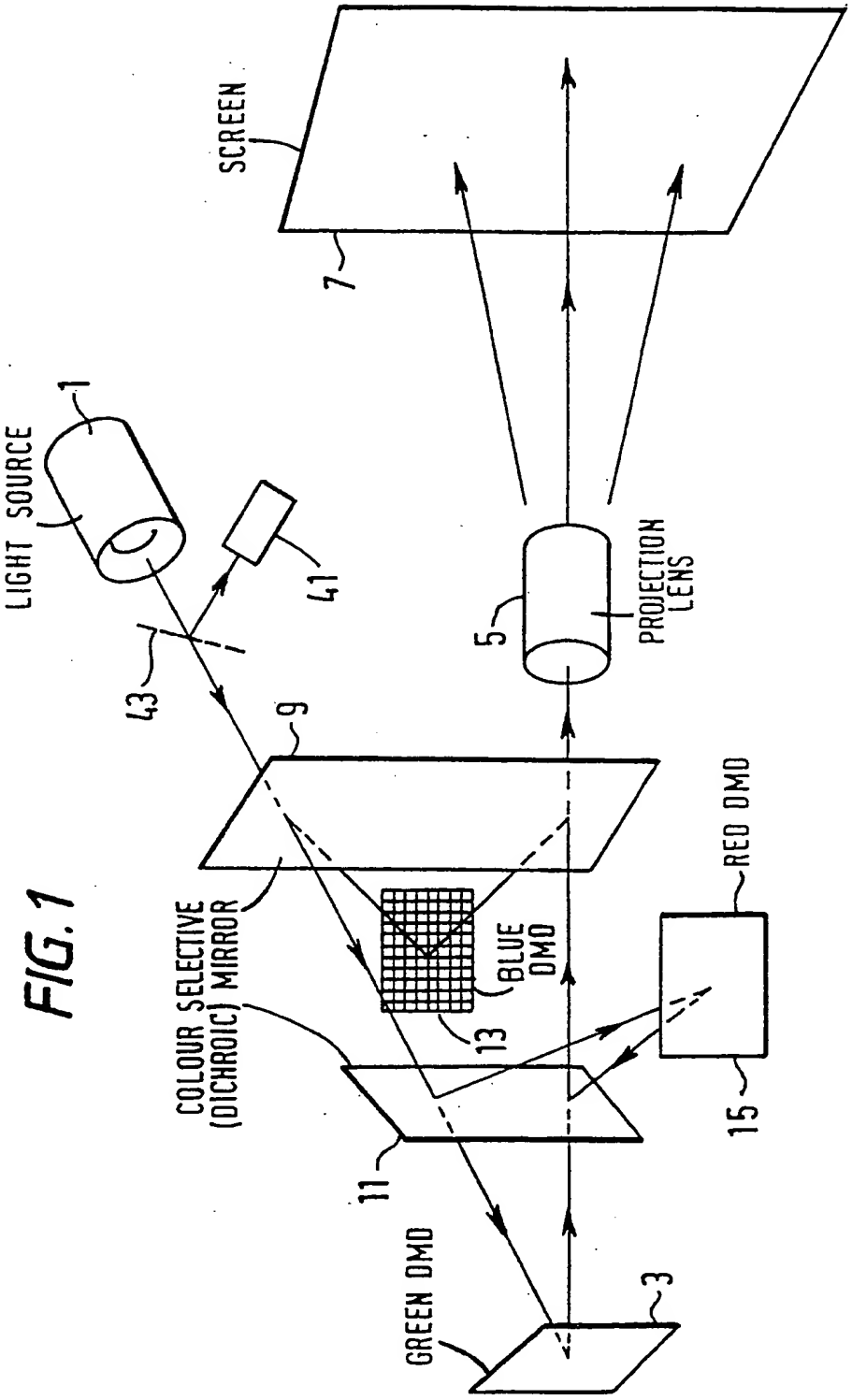

SCREEN
7
LIGHT SOURCE
1
41
43
5
PROJECTION LENS
9
RED DMD
COLOUR SELECTIVE (DICHROIC) MIRROR
BLUE DMD
13
15
11
GREEN DMD
3

FIG. 1

FIG. 2

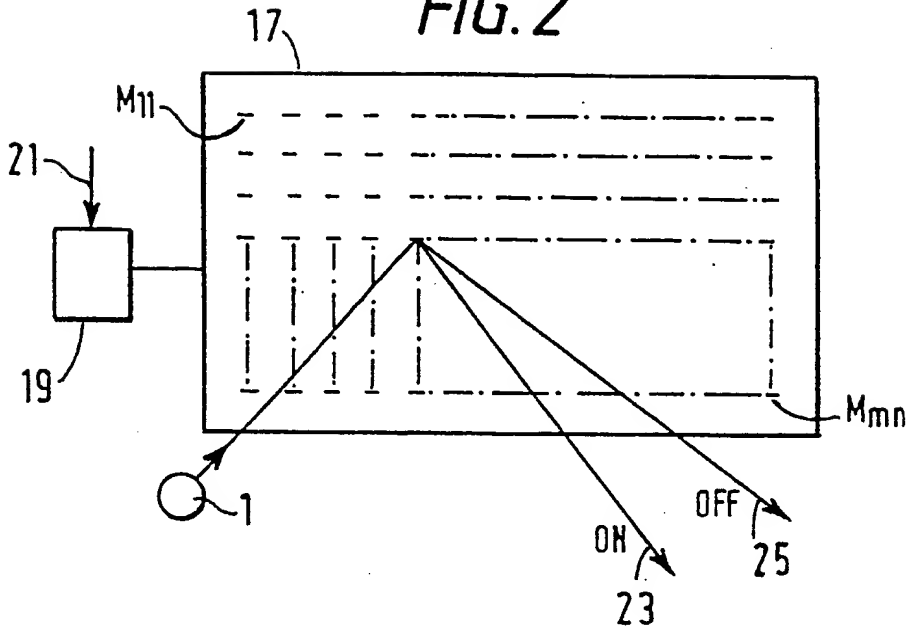
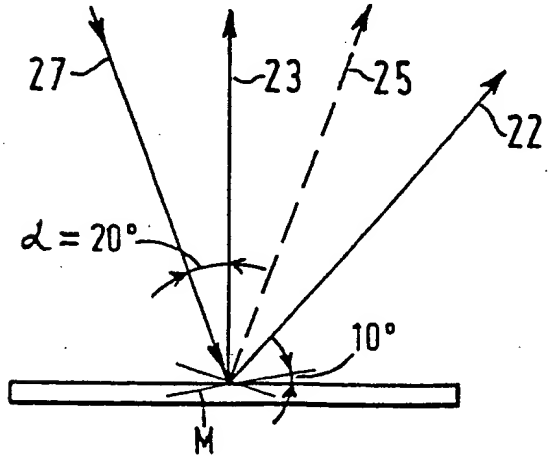


FIG. 3



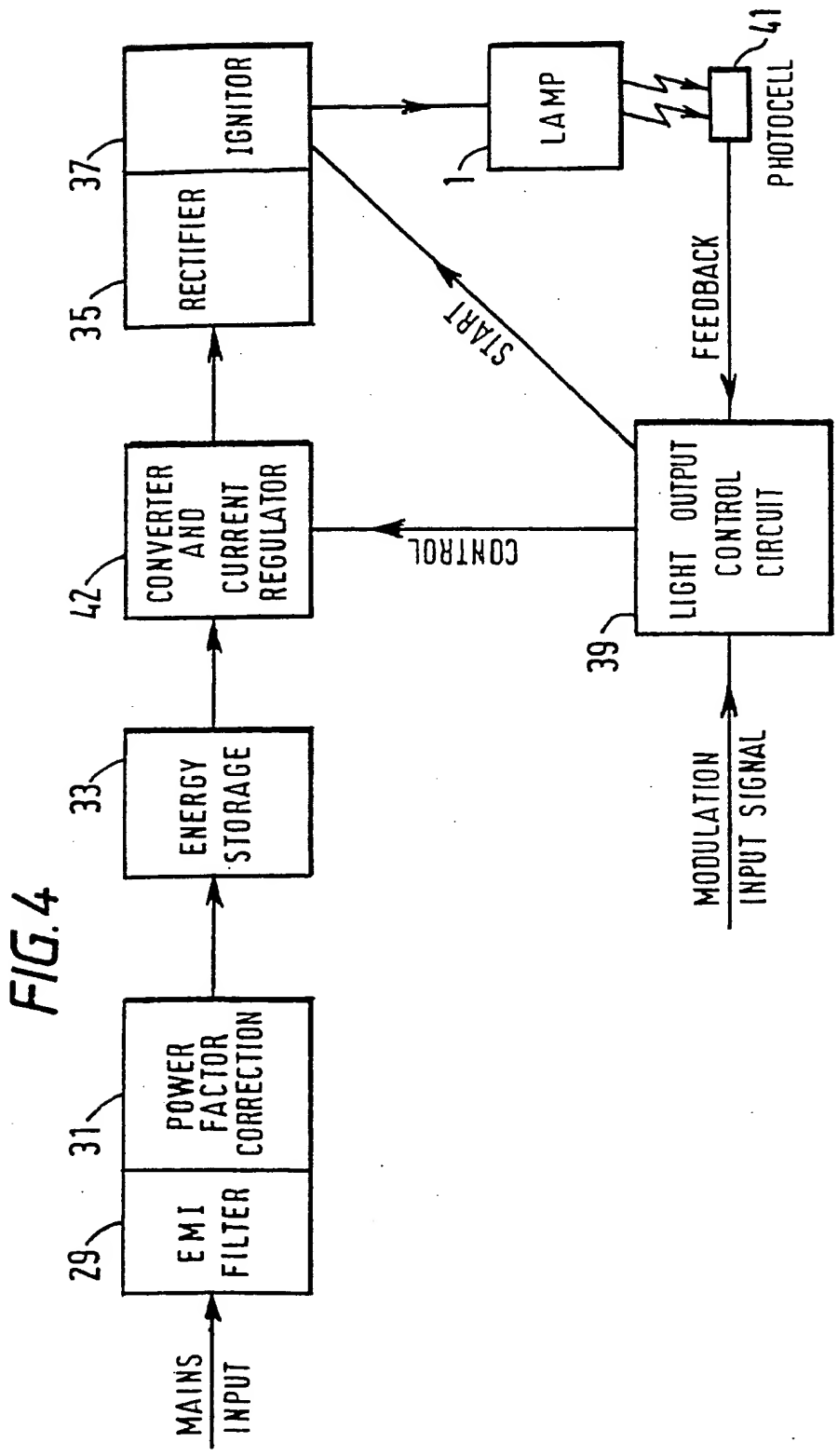
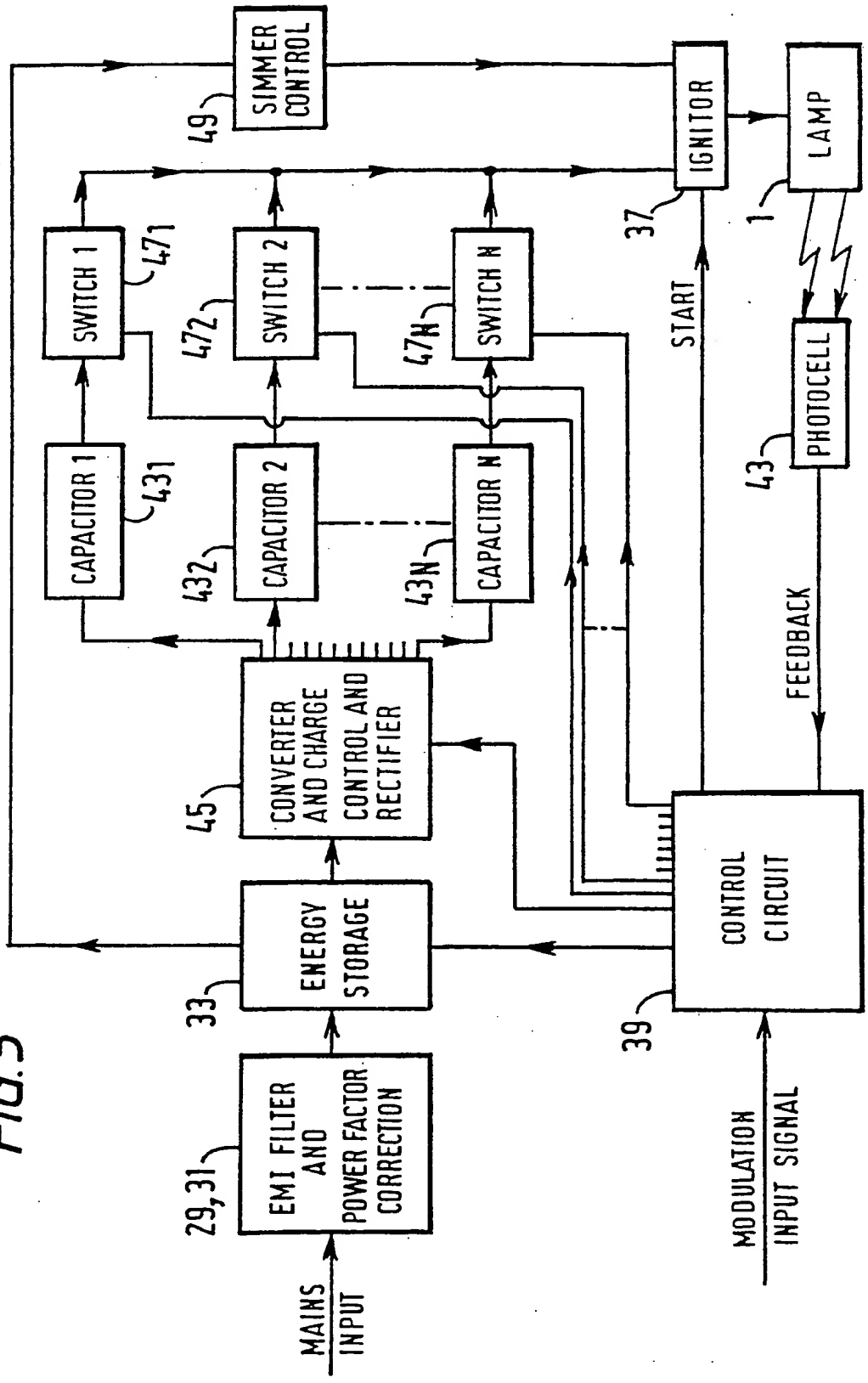

MAINS INPUT
29
EMI FILTER
31
POWER FACTOR CORRECTION
33
ENERGY STORAGE
42
CONVERTER AND CURRENT REGULATOR
35
RECTIFIER
37
IGNITOR
1
LAMP
41
PHOTOCELL
FEEDBACK
START
CONTROL
39
LIGHT OUTPUT CONTROL CIRCUIT
MODULATION INPUT SIGNAL

FIG. 4


MAINS INPUT
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EMI FILTER AND POWER FACTOR CORRECTION
33
ENERGY STORAGE
45
CONVERTER AND CHARGE CONTROL AND RECTIFIER
CAPACITOR 1
431
CAPACITOR 2
432
CAPACITOR N
43N
SWITCH 1
471
SWITCH 2
472
SWITCH N
47N
49
SIMMER CONTROL
37
IGNITOR
1
LAMP
START
43
PHOTOCELL
FEEDBACK
39
CONTROL CIRCUIT
MODULATION INPUT SIGNAL

FIG.5

INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/GB 93/02254

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 G09G3/34 H04N3/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 G09G H04N H05B G02B G09F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	EP,A,0 261 896 (THORN EMI PLC) 30 March 1988 see Abstract see column 4, line 24 - column 5, line 47; figures 1-3	1-4,6,7 5,8,10
Y	DATABASE INSPEC INSTITUTE OF ELECTRICAL ENGINEERS, STEVENAGE, GB Inspec No. 1710288 MILENIN V M ET AL 'On the possibility of enhancing the luminous efficacy of low-pressure discharge sources' see Abstract & SVETOTEKHNIKA (USSR), SVETOTEKHNIKA, APRIL 1981, USSR, 4, 6 - 8, ISSN 0039-7067, XPSER: SVETO	5

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

2

Date of the actual completion of the international search	Date of mailing of the international search report
16 February 1994	02. 05. 94

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax (+ 31-70) 340-3016	Corsi, F

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A,5 111 115 (BALL ET AL.) 5 May 1992 see Abstract see column 10, line 1 - line 35; figures 3,9	8
Y	US,A,4 464 606 (KANE) 7 August 1994 see Abstract see figure 1	10
A	GB,A,2 004 090 (COBERLY & ASSOCIATES) 21 March 1979 see Abstract	9

INTERNATIONAL SEARCH REPORT

In ational application No.
PCT/GB93/02254

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see annexed sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searches without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-11

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

INVITATION TO PAY ADDITIONAL FEES

International application No.
PCT/GB93/02254

1. Claims 1-11: Modulation of a light source in synchronization with temporal modulation of a light spatial modulator.

2. Claims 12-19: Modulation of a discharge lamp in a way to increase its efficiency.

The special technical feature of the 1st invention is the modulation of the light source in combination with the time modulation of the spatial light modulator (in order to achieve better low grey levels).
Instead the 2nd invention consists in modulating a discharge lamp in order to increase its efficiency.
The only technical link between the two inventions is the fact that a lamp is modulated, which is per se well known in the state of the art, as stated by the cited document n. 1.
This is why a-priori non-unity has been invoked.

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int ional Application No
PCT/GB 93/02254

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
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